Concrete Grinding Residue Characterization and Influence on Infiltration

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Concrete grinding residue (CGR) is a slurry byproduct created by concrete pavement maintenance operations. Disposal of CGR slurry is presently regulated on the basis of very minimal information. The least immediate expense is incurred by spreading CGR slurry directly on vegetated roadway ditches and embankments. The direct disposal impacts to environmental quality in terms of soil physical or chemical properties are not known. Five CGR materials from widely dispersed sites in the United States were analyzed for particle size distribution and evaluated with a suite of USEPA physical and chemical analyses. Values found for the parameters examined are not considered harmful. An infiltration column study was also conducted in which two CGRs were mixed at 8 and 25% by weight and also surface applied 2.5 mm deep with two contrasting (relatively fine and coarse textured) soils. With the finer soil, statistically ($p < 0.05$) significant decrease in infiltration time (increased infiltration rate) was associated with the 25% and surface-applied CGR treatments, compared with the untreated control soil. The results indicate that excessive application of CGR may increase water infiltration into soil in the short term. This should be kept in mind, but does not appear to be generally detrimental.

Grinding of concrete highway surfaces is widely used to improve ride and extend useful highway life. Highway concrete grinding typically uses diamond-impregnated grinding wheels stacked together on a shaft that produce a total grinding width ranging from 0.9 to 1.2 m. The thickness of the concrete that is removed is a function of the degree of highway roughness and can range from 1.6 to 12.7 mm. Water is introduced to the grinding wheels to increase their life expectancy, decrease dust emissions and increase worker safety (Akbar-Khanzadeh et al., 2007; Sheinbaum, 1962), and facilitate the movement of the grinding residue away from the grinding surface. The resultant concrete grinding residue (CGR) can be disposed of below the road shoulder at the site of grinding, collected and moved to a containment pond where it is then dewatered and the solids are transported to a landfill, or recycled (Dosho, 2008; Goodwin and Roshek, 1992). Assuming a bulk density of concrete of 2600 kg m^{-3} and a grinding depth 1.6 mm over an area 1 km long and 3.7 m wide (the width of interstate lanes in the United States), about 15 Mg of solid material would need to be disposed of per kilometer per driving lane. A good overview of the diamond grinding process can be found in Shanmugam (2004).

Currently, disposal methods in the United States are state specific. For example, the North Dakota Department of Transportation (DOT) allows the disposal of the CGR below the road's shoulder (B. Darr, personal communication, North Dakota DOT, 2010) while, in contrast, the California DOT requires grinding contractors to dispose CGR offsite, often in containment ponds and landfills (T. Pyle, personal communication, California DOT, 2010). The direct disposal of CGR to roadside soils has become an environmental issue for some states, including Nebraska, which is currently changing regulation to require a permit for land application (Nebraska Department of Environmental Quality, 2010).

The composition of the concrete, the quality of water used, and the presence of organic compounds on the highway surface will dictate the potential hazards of the CGR. One of the main concerns with applying CGR to soils is the liming effect and subsequent increase in soil pH. Soil pH increased from 6.3 to as much as 9.4 along one roadside in the state of Washington (Shanmugam, 2004). Trace metal concentrations in the soils alongside roadways are often elevated above background concentrations due

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Abbreviations: 10/CA, California interstate highway 10 site; 69/MI, Michigan interstate highway 69 site; 75/NE, Nebraska highway 75 site; 82/WA, Washington interstate highway 82 site; 94/MN, Minnesota interstate highway 94 site; CGR, concrete grinding residue; DOT, Department of Transportation.

to anthropogenic activities other than CGR application (Ho and Tai, 1988; Gratani et al., 1992; Garcia and Millan, 1998; Shanmugam, 2004) and thus quantifying the impact of these metals on plants and soils can be difficult. In addition, in roadside areas that have shallow soils (Kohl et al., 1994) the movement of CGR materials to groundwater may also be of concern.

Given the extreme fineness of the CGR materials (<0.5 to 5 μm according to Yassin et al., 2005), the plugging of soil pores and a subsequent decrease in infiltration of water may occur (Agassi et al., 1981). This could be favorable from an engineering perspective of limiting water in subgrade materials. However, depending on the electrolyte concentration of the CGR, infiltration rates may actually increase due to a compression of the electric double layer (Favaretto et al., 2006). To better understand the potential environmental impact of adding CGR to roadside ditch soils, the objectives of this study were (i) to characterize some of the chemical and physical properties of CGR that may relate to environmental impact, and (ii) to determine the impact of CGR on soil water infiltration rates.

Materials and Methods

The two soils used for this study were Fargo silty clay (fine, smectitic, frigid Typic Epiaquert) and Wyndmere fine sandy loam (coarse-loamy, mixed, superactive, frigid Aeric Calciaquoll). The Fargo soil was collected near Fargo, ND, and was currently being used for roadway construction. Particle size analysis in our laboratory indicated 112 g kg^{-1} sand (0.05 < d < 2.0 mm), 436 g kg^{-1} silt (0.002 < d < 0.05 mm), and 452 g kg^{-1} clay (d < 0.002 mm). The Wyndmere soil was collected from the Albert E. Ekre Grassland Preserve located in southeast North Dakota. This soil was sandy loam and consisted of 726 g kg^{-1} sand (0.05 < d < 2.0 mm), 153 g kg^{-1} silt (0.002 < d < 0.05 mm), and 122 g kg^{-1} clay (d < 0.002 mm). For both soils the 0- to 30-cm depth was collected, air-dried, and ground to pass

a 2-mm sieve. Soil pH, organic matter, and electrical conductivity values, determined at the North Dakota State University Soil Testing Laboratory, for the Fargo soil were 8.0, 31 g kg^{-1}, and 1.6 dS m^{-1}, respectively, and for the Wyndmere soil were 6.0, 27 g kg^{-1}, and 0.2 dS m^{-1}, respectively.

Samples of CGR slurries were obtained from five sites representing a broad geographical distribution within the United States: Interstate highway 10 in Los Angeles, CA (10/CA); Interstate highway 94 near Fergus Falls, MN (94/MN); highway 75 near Elkhorn-Bellevue, NE (75/NE); Interstate 82 in Washington State (82/WA); and Interstate 69 in Michigan (69/MI).

Physical and chemical analyses of both the solution phase and solid phase of the CGR were submitted by Terracon Consulting (Naperville, IL) to First Environmental Laboratories, Inc. (Naperville, IL) and are listed in Table 1 and Table 2. In addition, each CGR was analyzed for 16 polynuclear aromatic hydrocarbons (PAHs) by the above laboratory using USEPA Method 8270C. These PAHs are associated with fuel and oil storage, the production and use of asphalt, transportation, and the processing, use, and disposal of fuels (Wilson and Jones, 1993). They included acenaphthene, acenaphthylene, anthracene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, chrysene, dibenzo[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-cd]pyrene, naphthalene, phenanthrene, and pyrene.

Particle size analysis of the CGRs was performed in duplicate by sieving and pipette (Gee and Bauder, 1986). The solid phase of the CGR had calcium carbonate equivalence (%CaCO$_3$) values (determined by Ward Laboratories, Kearney, NE) of 16.4 and 27.7 for 10/CA and 94/MN, respectively.

Ponded infiltration under falling head conditions was measured. The infiltration columns used (Fig. 1) were designed to apply a water head nearly instantaneously and without turbulence or drop impact. This avoided producing suspended soil

Table 1. Physical and chemical parameters of the solution phase of concrete grinding slurry from U.S. roadways.

Parameter	U.S. roadway identification and location†				
	10/CA	94/MN	82/WA	69/MI	75/NE
pH‡	12.5	11.8	11.6	12.2	11.6
TDS§ (mg L^{-1})	3040	5430	1420	4100	3580
TS¶ (%)	21.7	15.5	20.3	40.9	48.1
Hg# (μg L^{-1})	BRL††	BRL	BRL	BRL	BRL
As‡‡ (μg L^{-1})	BRL	BRL	17	BRL	BRL
Ba‡‡ (μg L^{-1})	BRL	BRL	BRL	BRL	BRL
Cd‡‡ (μg L^{-1})	BRL	BRL	BRL	BRL	BRL
Cr‡‡ (μg L^{-1})	98	33	35	17	36
Pb‡‡ (μg L^{-1})	BRL	BRL	21	BRL	BRL
Se‡‡ (μg L^{-1})	BRL	BRL	BRL	BRL	BRL
Ag‡‡ (μg L^{-1})	BRL	BRL	BRL	BRL	BRL

† 10/CA, California interstate highway 10 site; 69/MI, Michigan interstate highway 69 site; 75/NE, Nebraska highway 75 site; 82/WA, Washington interstate highway 82 site; 94/MN, Minnesota interstate highway 94 site.

‡ Determined using Standard Method 4500H+,B.

§ TDS, total dissolved solids by Standard Method 2540C.

¶ TS, total solids by Standard Method 2540B.

Determined using USEPA Method 7470A.

†† BRL, below report limit (for Hg, As, Ba, Cd, Cr, Pb, Se, and Ag the BRLs were 0.5, 2, 1000, 1, 1, 2, 2, 1 μg L^{-1}, respectively).

‡‡ Determined using USEPA Method 6020A/6010B.

particles and subsequent soil sealing. All experiments were conducted near 25°C, using 5 mmol L^{-1} $CaSO_4$ solution. The infiltration apparatus was previously described by Prunty and Bell (2008).

The two soils and two solid-phase CGR sources (10/CA and 94/MN) were tested in the infiltration experiments. Four treat-ments were used, designated as 8% mix (symbol = A), 25% mix (symbol = B), 2.5-mm layer (symbol = L), and control (symbol = N). Total soil column length was 15 cm for all columns, packed in five 3-cm segments of air-dry soil. The soils were packed to bulk densities of 1.22 and 1.36 g cm⁻³, for Fargo and Wyndmere soils, respectively. The "control" treatment columns were packed

Table 2. Physical and chemical parameters of the solid phase of concrete grinding slurry from U.S. roadways. All extractions and analyses were done using USEPA Method 6010B unless otherwise noted.

Parameter	U.S. roadway identification and location†				
	10/CA	94/MN	82/WA	69/MI	75/NE
Total cyanide‡ (mg kg⁻¹)	BRL§	BRL	BRL	0.12	BRL
Total P¶ (mg kg⁻¹)	45.6	11.0	4.9	3.0	2.1
SO_4^{2-}# (soluble) (mg kg⁻¹)	1240	4130	2370	690	1390
Hg†† (ng g⁻¹)	BRL	BRL	170	BRL	BRL
Al (g kg⁻¹)	12.0	9.3	16.6	24.2	5.9
Sb (mg kg⁻¹)	BRL	BRL	5.9	BRL	BRL
As (mg kg⁻¹)	3.7	3.7	48.6	19.3	2.1
Ba (mg kg⁻¹)	70.2	219	101	169	140
Be (mg kg⁻¹)	0.4	0.6	0.4	2.4	0.3
Cd (mg kg⁻¹)	0.4	0.2	0.3	1.0	0.5
Ca (g kg⁻¹)	50.1	63.3	56.6	126	46.1
Cr (mg kg⁻¹)	16.3	17.1	20.6	43.5	9.2
Co (mg kg⁻¹)	26.7	11.9	12.6	13.7	9.2
Cu (mg kg⁻¹)	10.6	12.3	50.8	35.7	7.3
Fe (g kg⁻¹)	11.2	13.3	23.8	27.8	3.5
Pb (mg kg⁻¹)	15.7	2.2	3.1	9.0	2.5
Mg (g kg⁻¹)	5.4	16.1	5.4	51.3	2.5
Mn (mg kg⁻¹)	223	374	283	640	94.5
Ni (mg kg⁻¹)	7.7	11.1	20.4	34.2	8.4
Pt (mg kg⁻¹)	BRL	1.4	BRL	2.2	4.8
K (g kg⁻¹)	2.3	NR‡‡	1.2	3.5	1.5
Se (mg kg⁻¹)	BRL	BRL	BRL	BRL	BRL
Ag (mg kg⁻¹)	BRL	BRL	BRL	BRL	BRL
Na (g kg⁻¹)	1.5	NR	3.2	16.0	2.3
Th (mg kg⁻¹)	BRL	BRL	BRL	BRL	BRL
V (mg kg⁻¹)	27.1	24.1	53.5	70.8	10.9
Zn (mg kg⁻¹)	45.9	50.9	149	120	51.6
W (mg kg⁻¹)	BRL	BRL	BRL	BRL	NR
B§§ (mg kg⁻¹)	4.4	34.2	BRL	4.9	15.3
Mo§§ (mg kg⁻¹)	BRL	3.0	BRL	BRL	5.1
Sr§§ (mg kg⁻¹)	136	371	291	67.5	267
Sn§§ (mg kg⁻¹)	2.2	BRL	5.1	BRL	BRL
W§§ (mg kg⁻¹)	880	722	1100	89.7	233
Cr¶¶ (hexavalent) (mg kg⁻¹)	BRL	BRL	BRL	BRL	BRL
COD## (soluble) (mg kg⁻¹)	2210	380	889	270	389

† 10/CA, California interstate highway 10 site; 69/MI, Michigan interstate highway 69 site; 75/NE, Nebraska highway 75 site; 82/WA, Washington inter-state highway 82 site; 94/MN, Minnesota interstate highway 94 site.

‡ Determined using Standard Method 4500CN,C,E.

§ BRL, below report limit (for total cyanide, Hg, Sb, Pt, Se, Ag, Th, W, B, Mo, Sn, and hexavalent Cr the BRLs, at respective units noted in the table, were 0.1, 50, 1.0, 0.2, 0.1, 1.0, 3.6, 1.0, 1.0, 2.0, and 2.5, respectively).

¶ Determined using Standard Method 4500P,B,E.

Determined using USEPA Method 9038.

†† Determined using USEPA Method 7470A.

‡‡ NR, data not reported.

§§ Determined using USEPA Method 6020A.

¶¶ Determined using USEPA Method 7196A.

COD, chemical oxygen demand by USEPA Method 7196A.

Fig. 1. Infiltration progress in four 2.5-cm-diameter soil columns as used in this study.
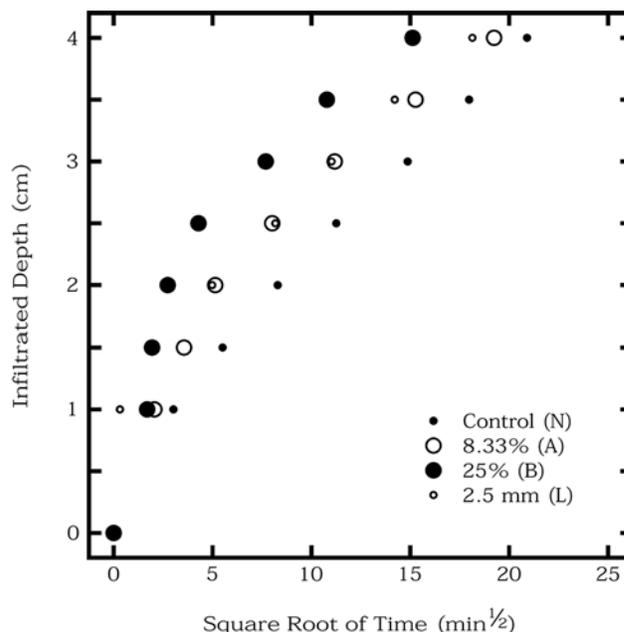

Fig. 2. Infiltrated depth vs. square root of time for a typical column (Fargo soil). Four treatments were used, designated as 8% mix (symbol = A), 25% mix (symbol = B), 2.5-mm layer (symbol = L), and control (symbol = N).

without any CGR. The 8% mix treatment consisted of mixing the soil packed into the top (near surface) 3 cm with 8% by weight of CGR. The 25% mix treatment used 25% CGR in the top 3 cm. The 2.5-mm-layer treatment had a 2.5-mm layer of CGR packed on the column surface.

Four columns were available for packing. The four were packed with a randomized treatment by a single operator who packed all four as a set. This was done to minimize packing variability between treatments. Each column set used the same soil and CGR source. The infiltration runs on the four columns were conducted with 5-min staggered start times, so that they were essentially run simultaneously. There were three replications of each soil–CGR combination. We recognize that packed column experiments, even with representative soils, are far from the ideal of site-specific field work. Notwithstanding this, this approach does provide applicable information and may be obtained efficiently.

To begin the infiltration run, the gate was rapidly withdrawn and a timer started. The water column thus was put into contact with the soil surface nearly instantaneously. The elapsed times that the water level in the ponding tube passed given levels were recorded at approximately every 5 mm, except when rapid initial decline prevented this. For all the infiltration runs the initial depth of ponding, when the gate was withdrawn, was 14.5 cm. In most instances infiltration was recorded until >4 cm of water had infiltrated. A set of columns during infiltration is shown in Fig. 1.

The depth of water infiltrated was plotted, Fig. 2 being typical, vs. the square root of elapsed time after the gate was withdrawn. Using square root of time as the independent variable (abscissa of Fig. 2) for infiltration analysis is justified because horizontal infiltration theory (Hillel, 1998) predicts cumulative infiltration proportional to the square root of time. Simple vertical infiltration theory (Hillel, 1998) adds a linear time term, but at small times the square root term dominates. Thus, the square root of time to infiltrate 3.5 cm of water was appropriate for statistical analysis. The analysis of variance (Table 3; SAS Institute, 1982) was of the split-plot (Steel and Torrie, 1960) type, conducted separately for each soil.

Results

Characterization of Concrete Grinding Residue

The pH of the solution phase of the CGR ranged from 11.6 to 12.5, independent of location (Table 1). Although these pH levels are elevated compared with agricultural soils in the northern Great Plains (pH 5.5 to 8.2), they are within the characteristic toxicity limit (40 CFR 261) (USEPA, 2010). With respect to the solution phase, As, Ba, Cd, Cr, Pb, Se, and Ag were also below 40 CFR 261 standards (USEPA, 2010) (Table 1). Total solids in these residues ranged from 15.5 to 48.1% and the average total dissolved solids concentration was about 3500 mg L^{-1} (Table 1).

In general, nearly all of the elements present in the solid phase were below the ranges reported in surface soils (Chen et al., 1999; Sparks, 2003; Essington, 2004; Ozaki et al., 2004) and the coal combustion byproduct, flue gas desulfurization gypsum (DeSutter and Cihacek, 2009) (Table 2). Mercury was elevated in the 82/WA sample (170 ng g^{-1}) above what would be expected in surface soils. In North Dakota soils the average total Hg concentration is about 32 ng g^{-1} (DeSutter et al.,

Table 3. Analysis of variance of the infiltration experiment for each of the soils. Table symbols are C = concrete grinding residue sources, T = treatments.

Source	df	Fargo		Wyndmere	
		MS	F	MS	F
C	1	61.63	4.52 NS†	11.59	29.3**
Error C	4	13.62		0.39	
T	3	32.14	5.65*	0.61	NS
T × C	3	14.28	2.51 NS	0.27	NS
Error T	12	5.69		0.74	

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† NS, not significant.

2009). The average chemical oxygen demand ranged from 270 to 2210 mg kg^{-1} (Table 2).

None of the 16 PAHs analyzed for in this study were detected at the routine reporting limit set by the laboratory. Soils contaminated with PAHs have been shown to decrease the growth of legumes (*Lotus corniculatus* L., *Trifolium pratense* L., and *Trifolium repens* L.) compared with control soils (Smith et al., 2006) and thus concrete grinding operators should take precaution in areas having known spills or contamination so as to not introduce these compounds into the environment. Although not all of the elements and compounds analyzed for in this study were detected in the CGR, the lack of published data on this topic warrants the inclusion of this information here for further reference.

Particle size analysis (Fig. 3) of the CGR materials found that the diameter at 50% smaller (by mass) ranged from 11 to 50 μm. At 50-μm diameter, the fraction smaller ranged from 50 to 75%. Four of the CGRs had similar gradations, resulting in particle size distribution curves that did not cross. For these four CGRs, the fraction 0- to 5-μm diameter ranged from 20 to 32%. The 10/CA distribution curve, on the other hand, crossed the other curves because 10/CA CGR was relatively poorly graded and had no particles <5 μm diameter. Overall, silt-sized particles were a major constituent of all five CGRs.

Characterization of Concrete Grinding Residue Impacts on Water Infiltration

The CGR sources and treatments significantly altered infiltration time, depending on the soil (Tables 3 and 4). With the Fargo soil, the N and A treatments had longer infiltration times than the treatments B and L (Table 4). Infiltration time was not significantly different because of treatment for the Wyndmere soil. Since for both soils the control treatment had the longest time (Fargo soil) or had time insignificantly different than the longest (Wyndmere soil), there is no indication that CGR generally slows infiltration. For both soils, infiltration time was longer with the 94/MN CGR, compared with the 10/CA CGR, but the difference was significant only with the Wyndmere soil.

Discussion

An experimental unit in the infiltration experiment was a packed column. The number chosen to represent an experimental unit was based on time at 3.5-cm cumulative infiltration, which we believe to be generally representative, based on our preliminary review of all the data and a subsequent nonparametric analysis. Also, use of the square root of the time is consistent with simple infiltration theory, as noted previously. Finally, the 3.5-cm quantity was near the maximum amount of recorded infiltration for any run, thus representing the most widely based infiltration index available for the data set as a whole.

But, discussing additional aspects of the data is also appropriate since there are various options to represent the overall process. Infiltration itself depends on numerous underlying physical and chemical properties of the soil. Influential properties are the soil water characteristic, soluble salt content, bulk density, porosity, and hydraulic conductivity. Some of these
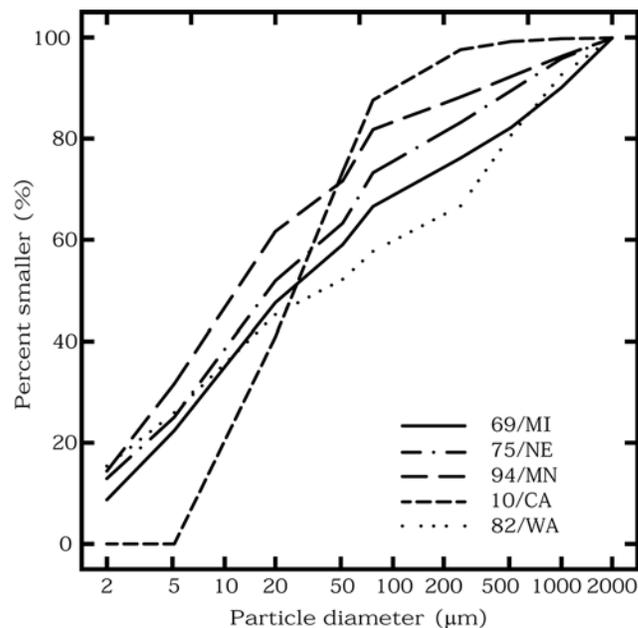
Fig. 3. Particle size distributions for the five concrete grinding residues from U.S. roadways. Sites: 10/CA, California interstate highway 10; 69/MI, Michigan interstate highway 69; 75/NE, Nebraska highway 75; 82/WA, Washington interstate highway 82; 94/MN, Minnesota interstate highway 94.

properties may be influenced in a "favorable" direction by the CGR materials while others may be negatively impacted. Infiltration measurements integrate the effects of several properties, are often considered important in assessing environmental conditions, and are more accessible than characterizing the complete array of underlying properties. Slower infiltration is the condition that would most commonly be considered undesirable, but an unusual site-specific environment could possibly cause faster infiltration to be less favored.

Treatments L and B, overall, and significantly so for Fargo soil, had the lowest infiltration (3.5 cm) times. This order and the typical result is well illustrated by Fig. 2. However, treatments L and B in some column-set runs showed a tendency to "flatten out" (progress to slower infiltration rates over time) more than the N and A treatments. This seems to indicate that

Table 4. Means of the square root of time (min$^{1/2}$) for treatments and concrete grinding residues (CGRs) from U.S. roadways in the infiltration experiment. The means were compared with Duncan's multiple range test (SAS Institute, 1982) with means in the same group followed by the same letter not significantly different while different letters indicate significance at p < 0.05.

Treatment or CGR†	Mean root of time (min$^{1/2}$)	
	Fargo	Wyndmere
Treatment		
N	15.80 A	4.77 A
A	15.42 A	5.00 A
L	12.31 B	4.25 A
B	11.10 B	4.75 A
CGR		
94/MN	15.26 A	5.39 A
10/CA	12.06 A	4.00 B

† Treatments: N, control; A, 8% mix; B, 25% mix; L, 2.5-mm layer. CGRs: 10/CA, California interstate highway 10 site; 94/MN, Minnesota interstate highway 94 site.

the influence of treatments L and B, compared with the others, fades as time goes on. Could longer-term studies result in a reversal of the treatment rankings found in this preliminary study? The possibility seems remote. Much more likely would be the disappearance of any statistically significant differences.

The 10/CA CGR was coarser than the 94/MN CGR, possibly resulting in the longer infiltration time associated with the 94/MN CGR. This, however, is a hypothesis that requires additional investigation.

Conclusions

Current CGR materials, at least those represented in this study, do not present a hazard. While direct deposition of the CGR machine product on the vegetated parts of highway rights-of-way may be unsightly to some, the environmental impact is negligible. We recommend that any method for disposal of CGR be justified as to its purpose and clearly stated.

Changes in concrete aggregate composition could alter this picture in the future. In recent years fly ash and other non-traditional materials have been introduced into concrete mixtures (Mroueh et al., 2001; Ferreira et al., 2003; Bertolini et al., 2004). Some of these materials have been shown to contain substantial amounts of substances, particularly metals, that are considered hazardous in some situations (Theis et al., 1978). It would be forward-looking to specifically record use of these materials for future reference so that a proper level of disposal of the CGR can be implemented. If use of a material is projected to cause future increased cost because grinding is then more expensive or prohibited, this should be considered in the preconstruction material selection process as a contributor to future costs. Adjustment of the grinding process to produce coarser CGR (more like 10/CA) might be beneficial.

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